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NONLINEAR SYSTEMS DYNAMICS IN CARDIOVASCULAR PHYSIOLOGY:
THE HEART RATE DELAY MAP AND
LOWER BODY NEGATIVE PRESSURE

Final Report

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ABSTRACT

This report is a presentation of a preliminary study of the applicability of nonlinear dynamic systems analysis techniques to LBNP studies. In particular, the applicability of the heart rate delay map is investigated.

It is suggested that the heart rate delay map has potential as a supplemental tool in the assessment of subject performance in LBNP test and possible in the determination of susceptibility to cardiovascular deconditioning with spaceflight.

INTRODUCTION

The human cardiovascular system is a very complicated, highly nonlinear, dynamic system. As such, it is a primary candidate for analysis using the techniques of chaos theory which have evolved in the recent past in an attempt to understand the nature of deterministic systems whose outputs appear to be random.

One tool which has been used for discrete systems -- systems with outputs only at discrete times and described, at best, by difference equations, as opposed to systems with continuous time outputs and described by differential equations -- is the delay map. The delay map for discrete systems is analogous to the phase space trajectory for continuous systems. Each of these represents a description of the dynamic behavior of the variable under consideration.

This report discusses some of the findings of a preliminary study into the applicability of the delay map in the analysis of heart rate variation during lower body negative pressure (LBNP) tests. This study was performed in the Cardiovascular Laboratory, Space Biomedical Research Institute, NASA Johnson Space Center, as part of the NASA/ASEE Summer Faculty Fellowship Program 1990.

DATA ACQUISITION AND METHODOLOGY

The heart rate data used in this study was derived from data recorded during pre-bedrest, pre-syncopal LBNP tests. Actual data recorded included ECG (in most cases), blood pressures (systolic, diastolic, and mean), and chamber pressures (LBNP). Cardiac cycle duration (CCD) was calculated from the ECG and the blood pressure. Where available, the CCD from the ECG was used to determine the heart rate as a function of time. If CCD from the ECG was not available the CCD from the blood pressure was used. Heart rate was determined as the inverse of the CCD multiplied by 60 seconds per minute. The time sequence for the heart rate profile was determined by summing the CCDs. The recorded data was digitized and presented in worksheet format on floppy discs. Data on four subjects was available.

The heart rate delay map was constructed by comparing the heart rate after a twelve second delay with the heart rate before the delay, i.e., the present heart rate versus the heart rate twelve seconds ago. A simple program was written in the C language to search back through the heart rate data to determine the heart rate twelve seconds ago.

The heart rate delay map was then constructed by plotting the heart rate after the delay versus the heart rate before the delay.

RESULTS PRESENTATION AND DISCUSSION

The heart rate delay of twelve seconds represents the delay associated with autonomic nervous system control of the cardiovascular system primarily via the sympathetic and parasympathetic inputs to the SA node pacemaker of the heart. Several researchers (1,2) have shown through spectral analyses of heart rate data that there is a low frequency component of the spectrum at approximately 0.08 Hz corresponding to this delay. Based on these analyses the twelve second delay was used for this study.

The heart rate time profile of Subject A is shown in Figure 1. Superimposed on that profile is the LBNP. Each chamber pressure was maintained for approximately three minutes with the transitions taking only a few seconds. The LBNP test was terminated when the systolic blood pressure dropped below a given threshold and the heart rate ceased to increase or decreased. For Subject A the test was terminated after a few minutes at a LBNP of -50 mmHg.

Figures 2 through 6 present the heart rate delay map segmented according to the steady LBNPs for Subject A and Figure 7 shows the composite heart rate delay for Subject A. The baseline or atmospheric pressure case (Figure 2) indicates that the heart rate delay map is concentrated in a small region of the map. If the -20 mmHg condition (Figure 3) is also considered as a non-stressful situation and only an extension of normal, the heart rate delay map resembles what Goldberger (1), and others in the chaos literature, refer to as a strange attractor. This attractor pattern indicates that, although the heart rate is quite variable, after excursion away from the norm, the heart rate returns. Note the "butterfly pattern" of Figure 3.

Figures 4, 5 and 6 indicate that as the LBNP stress increases (lower LBNP) the heart rate increases, becomes more variable, and the excursions increase in magnitude and duration. Of significance is the decrease in variability of the map -- a concentrating of the map -- during the late -50 mmHg case and a decrease in the heart rate -- seen as the map trends down and to the right as the end of the test approaches.

One other subject presented a similar delay map.

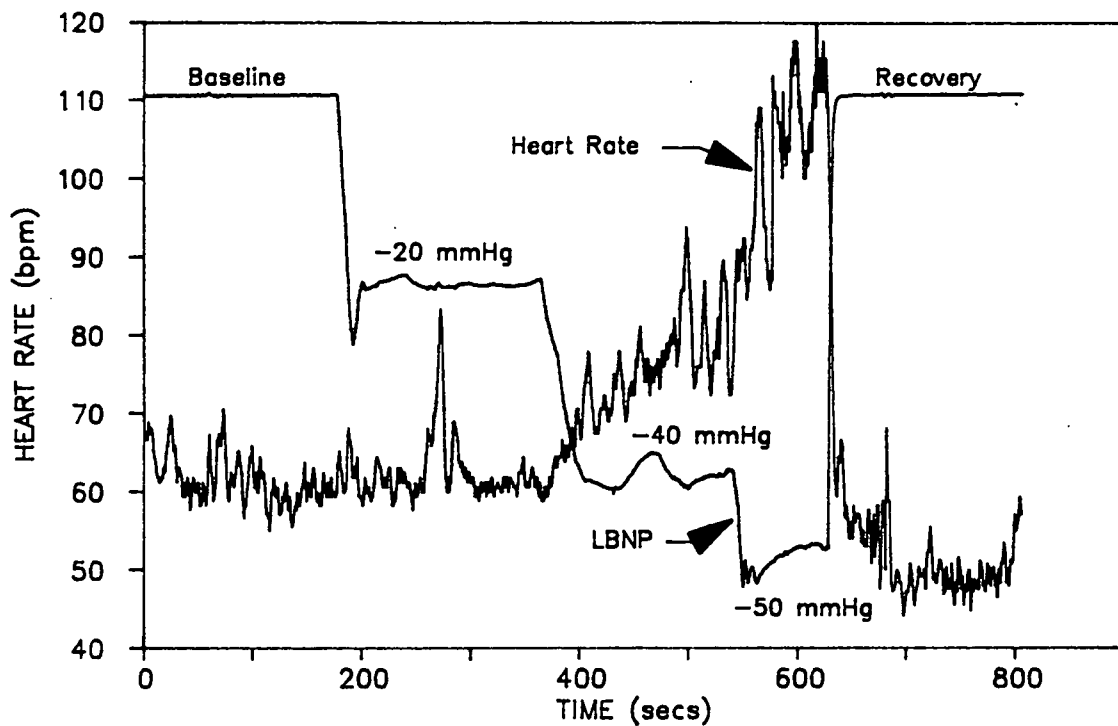


Figure 1.—
HEART RATE
SUBJ A, PRE-BEDREST, PRE-SYNCOPAL TEST

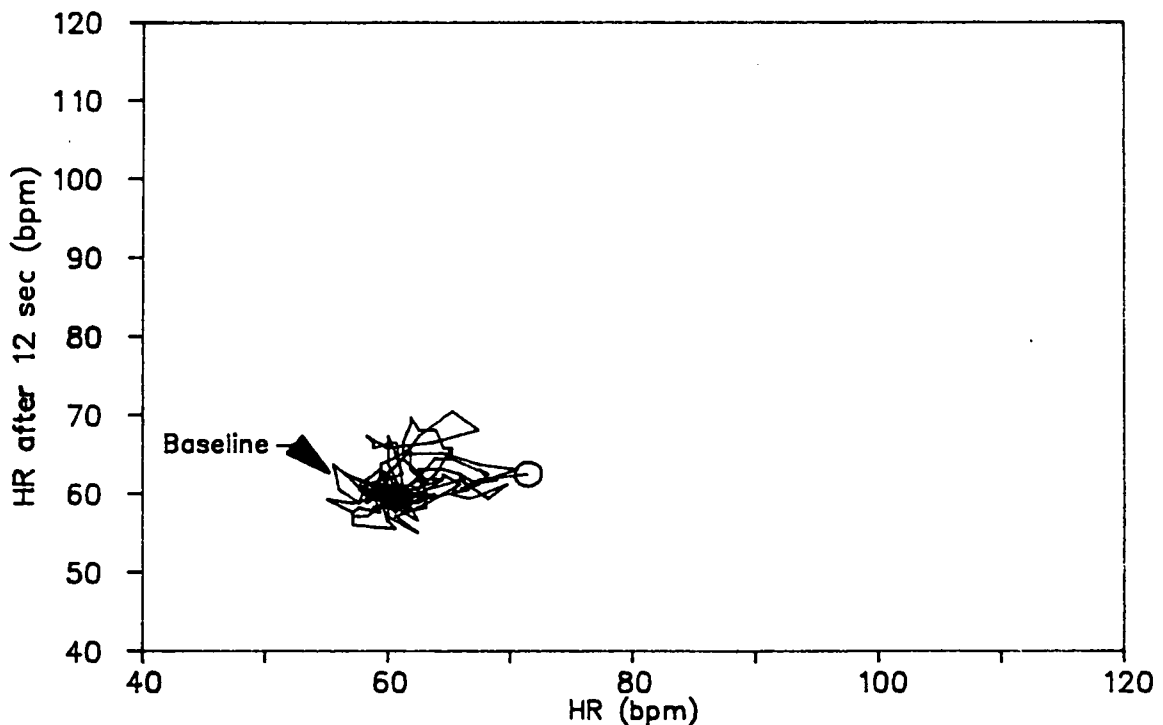


Figure 2.—
HEART RATE DELAY MAP
SUBJ A, PRE-BEDREST, PRE-SYNCOPAL TEST

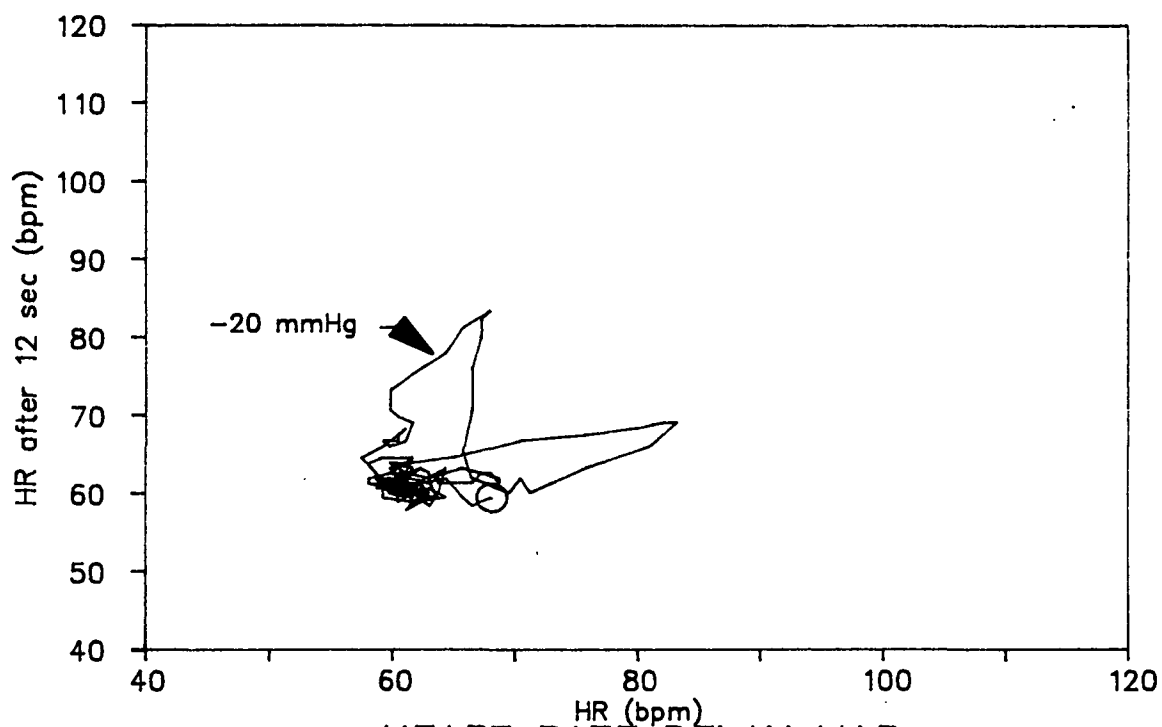


Figure 3.—
HEART RATE DELAY MAP
SUBJ A, PRE-BEDREST, PRE-SYNCOPAL TEST

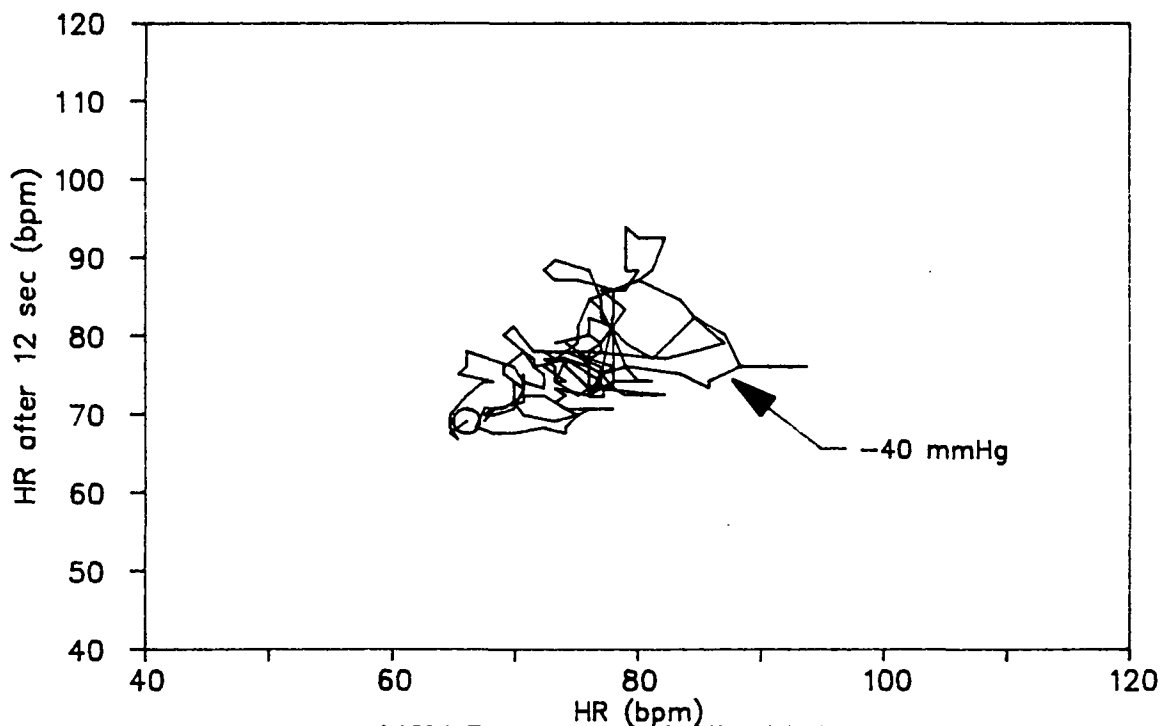


Figure 4.—
HEART RATE DELAY MAP
SUBJ A, PRE-BEDREST, PRE-SYNCOPAL TEST

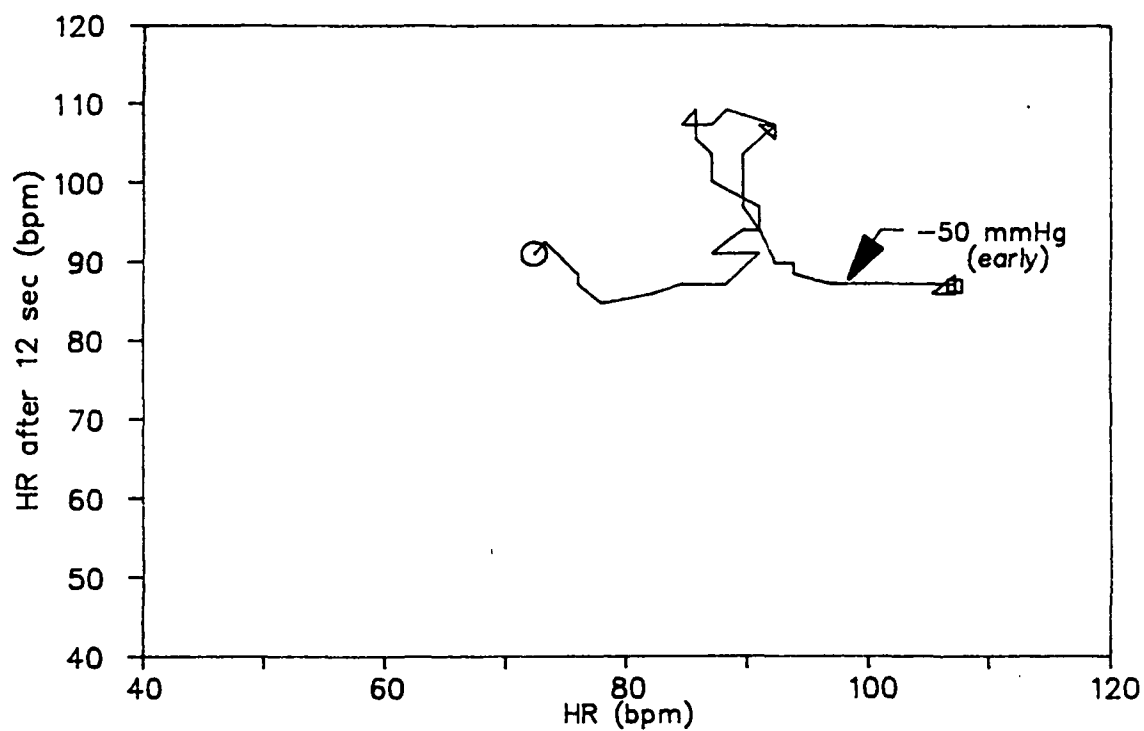


Figure 5.— HEART RATE DELAY MAP
SUBJ A, PRE-BEDREST, PRE-SYNCOPAL TEST

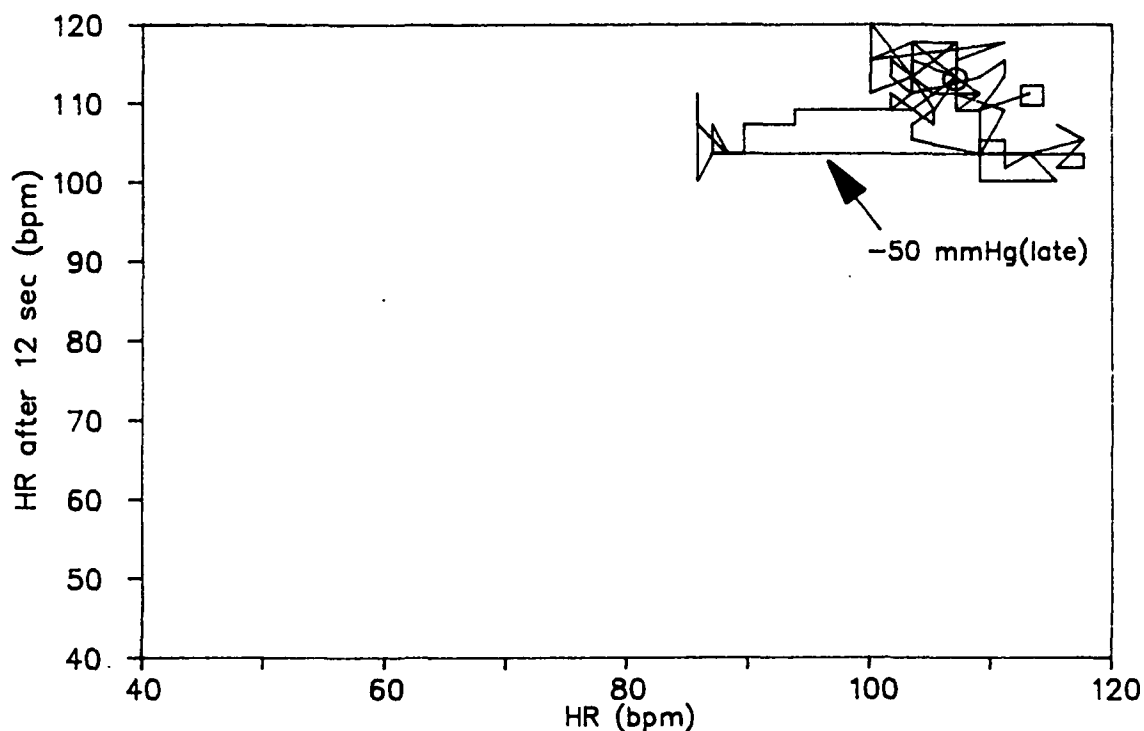


Figure 6.— HEART RATE DELAY MAP
SUBJ A, PRE-BEDREST, PRE-SYNCOPAL TEST

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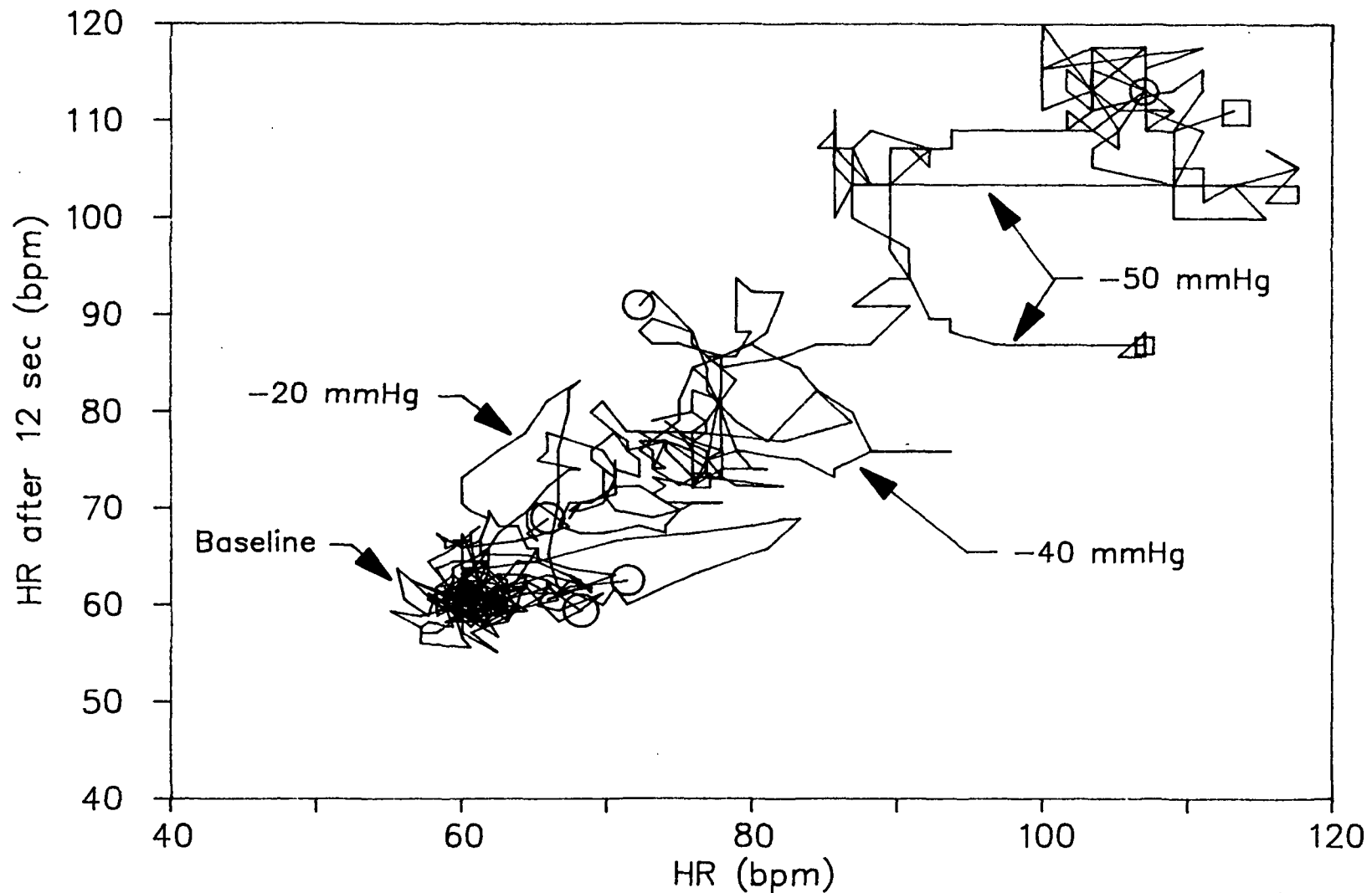


Figure 7.— **COMPOSITE HEART RATE DELAY MAP**
SUBJ A, PRE-BEDREST, PRE-SYNCO PAL TEST

Subject B (Figures 8 and 9) was able to withstand a greater LBNP stress as shown by LBNPs of -60 to -80 mmHg. Of significance in this study is the contrast to Subject A as seen in the decrease in heart rate variability (Figure 8) and a narrowing of the delay map (Figure 9) with LBNP stress. The geometric, rectangular pattern seen in the upper regions of heart rate (Figure 9) is a function of only two significant figures in the CCD.

Another subject presented a similar heart rate delay map to Subject B. It would appear from these two cases that as the subject is able to move to higher LBNP stress levels the heart rate delay map narrows.

CONCLUSIONS AND RECOMMENDATIONS

Although this was only a preliminary, cursory and small sample study, it appears that the heart rate delay map has potential as an analytic tool in LBNP studies. It would appear that the delay map has use as a supplemental aid in ascertaining the termination point of an LBNP test, particularly, if an on-line, real-time presentation is implemented. The delay map may also have potential as a predictor of subject susceptibility to cardiovascular deconditioning in spaceflight.

The following recommendations are made for further studies:

- 1) Longer time profiles of heart rate at constant LBNP should be analyzed. Such studies should give better indicators of strange attractors and deviations from them and the significance of such deviations.

- 2) The longer time profiles should also be subjected to spectral analyses and correlations done between changes in the heart rate delay map and the frequency spectrum.

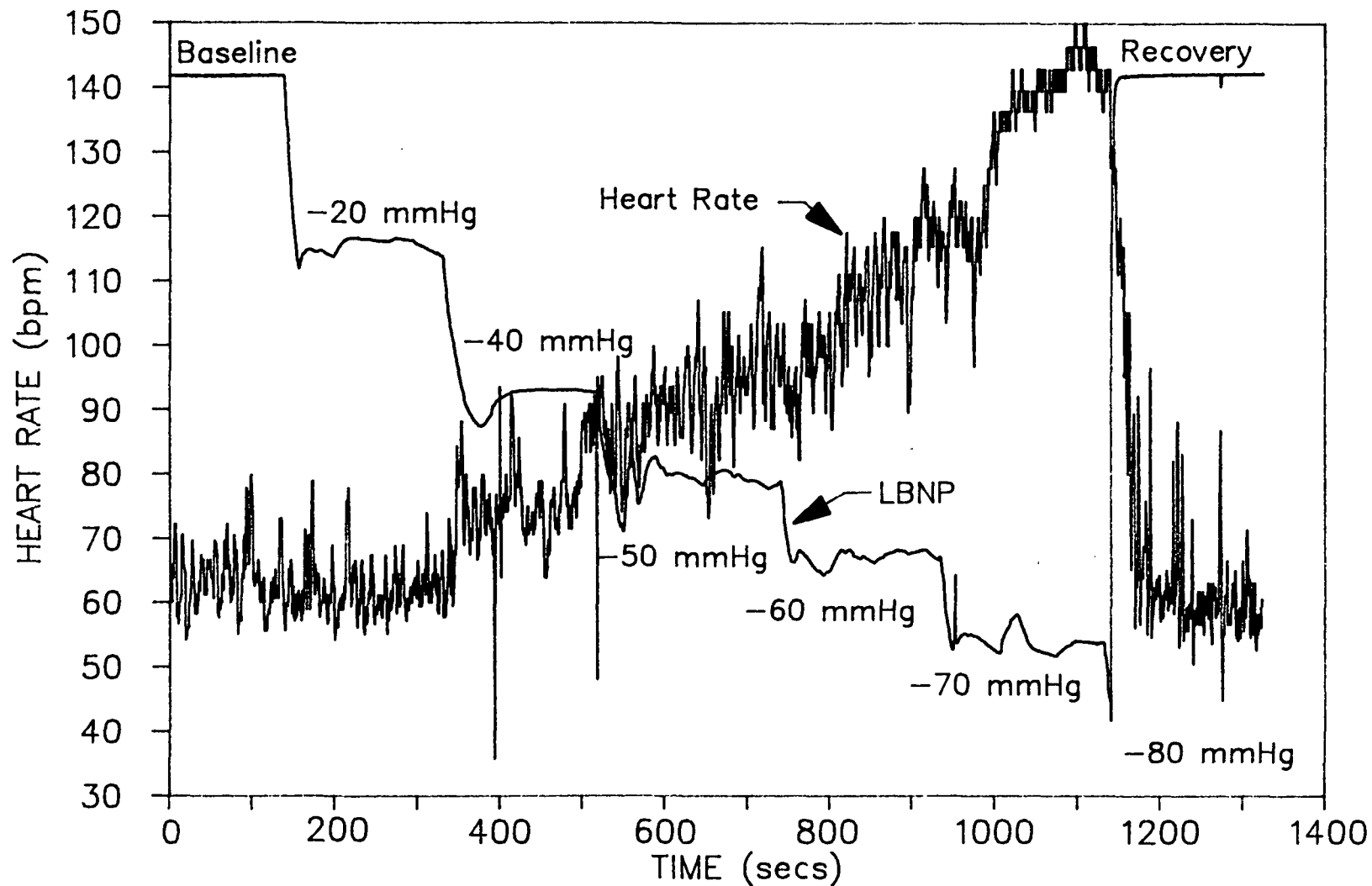


Figure 8.—

HEART RATE
SUBJ B, PRE-BEDREST, PRE-SYNCOPAL TEST

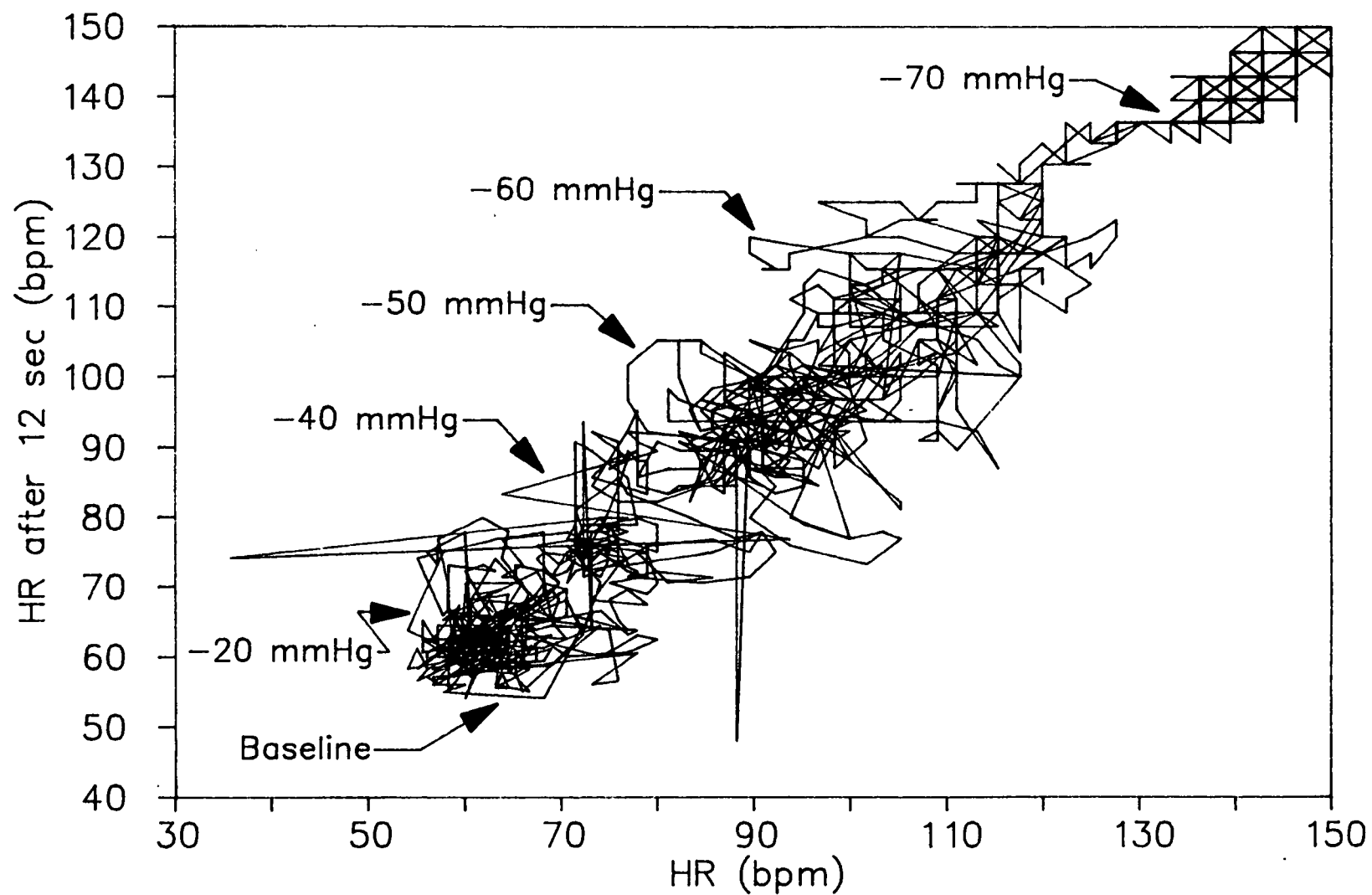


Figure 9.— **HEART RATE DELAY MAP**
SUBJ B, PRE-BEDREST, PRE-SYNCO PAL TEST

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